CMOS APS image sensor with ultra-high-linear-dynamic-range utilizing dual output

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Abstract

We report a 64x64 element CMOS active pixel sensor (APS) with ultra-high-dynamic-range linear output. The chip features a new architecture enabling two samples per pixel per frame. When we use the dual sample architecture, each pixel in the field of view can have two exposure times, enabling a large increase in the dynamic range. We obtained 108dB dynamic range with the array (and expect to obtain 126dB for imagers with 512 vertical lines). This approach enables us view a scene with a wide range of intrascene illumination levels without saturating the sensors or having the output be too low and overwhelmed by noise.

In the traditional CMOS APS design, a particular row is selected for readout. The sensor data from the selected row is copied simultaneously for all columns onto a sampling capacitor bank at the bottom of the columns. The pixels in the row are then reset and a new integration is started. The capacitor bank is then scanned sequentially for readout. This scan completes the readout for the selected row. The next row is then selected and the procedure repeated (see Fig. 1).

The architecture of the new approach is shown in Fig. 2. In the new architecture, a second column parallel signal chain circuit has been added to the upper part of the sensor. As before, row n is selected for readout and copied into the lower capacitor bank. Row n is reset in the process. However, immediately following, row n-A is selected and copied into the upper capacitor bank. Row n-A is also reset as a consequence of being copied. Both capacitor banks are then scanned for readout. The output data thus contains two sets of pixel data; one taken with integration time $T1_{int}$, and the second with time $T2_{int}$. The dynamic range of the sensor is extended by the factor $T1_{int}/T2_{int}$. For N= 1024 and A= 1, the dynamic range of the sensor can be extended by 10 bits to a total of 23 bits. Each image is read twice. The bright portions of the image are viewed best through the short integration time (upper) column parallel signal chain, and darker portions of the image are viewed best through the long integration time (lower) column parallel signal chain. A scene ‘which would appear saturated by the long integration time, can be managed by using the short integration time.

The chip was successfully fabricated and tested. It was implemented as an array of 64 x 64 photodiode-type APS elements using the HP 1.2 μm n-well process available through the MOSIS service. Functional testing of the multiple sampling circuitry confirmed the operability of the two outputs. Two images were obtained from the chips outputs. One represented the image with the long integration time, the second with the shorter . The ratios were varied and different dynamic ranges were achieved. Fig. 3 describes the outputs representing a long integration time (right column) which is 15/16 of the original integration time, while the short integration time (left column) was of the remaining 1/16 of the original integration time for different illumination levels. This ratio of 15:1 achieves an increase of 3.75 bits in the dynamic range. The outputs are from pixels that are separated by 4 rows and read out simultaneously. From top to bottom, it is shown that at first the long integration time is suitable for the light intensity, while the image from the short integration time is obscured by the noise. Gradually, with increasing light intensity two images appear, while the one with the long integration time begins to saturate. Then the short integration time is more suitable to the light level and that image carries the interesting information from the scene.

The output as a function of integration time in log-log scale is shown in Fig. 4. As can be observed, we have operated the dual sampling with ratio 63:1 of integration times - the maximum achievable with this 64 row imager. Thus, dynamic range was extended to 108dB, while for a 512x512 imager we expect to obtain 126dB.

In conclusion, an APS image sensor with dual outputs for increased dynamic range has been designed, fabricated and tested. An innovative approach to increase the dynamic range was described and demonstrated. The design approach does not affect the fill factor achieved, since the added circuitry resides in the periphery. The result is also acquired in real time, such that we have the wide dynamic range output during the frame readout (although there is a latency of part of the frame for the additional information). The excellent linearity of the re-sampling operation, bound together with optimal spatial resolution achievable in the pixel design, will also permit the usc of the architecture in high performance detector arrays for imaging and also non-imaging applications, such as spectroscopy, where very large dynamic range must be accommodated.

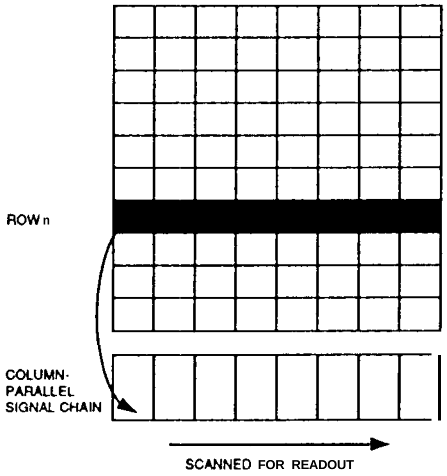


Fig. 1. Traditional APS readout.

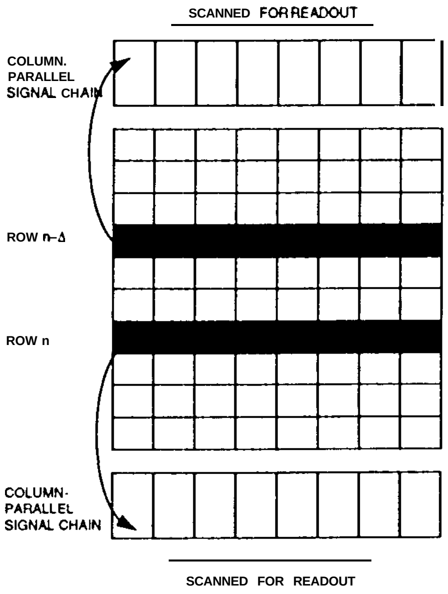


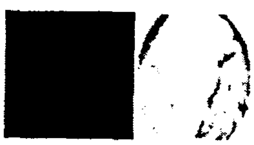
Fig. 2. Dual sample readout

I

II

III

IV



V

VI

Fig. 3. Sensor outputs with two exposure times with ratio of 15:1. The two outputs are 4 rows apart. Dynamic range was improved by 3.7.5 bits.

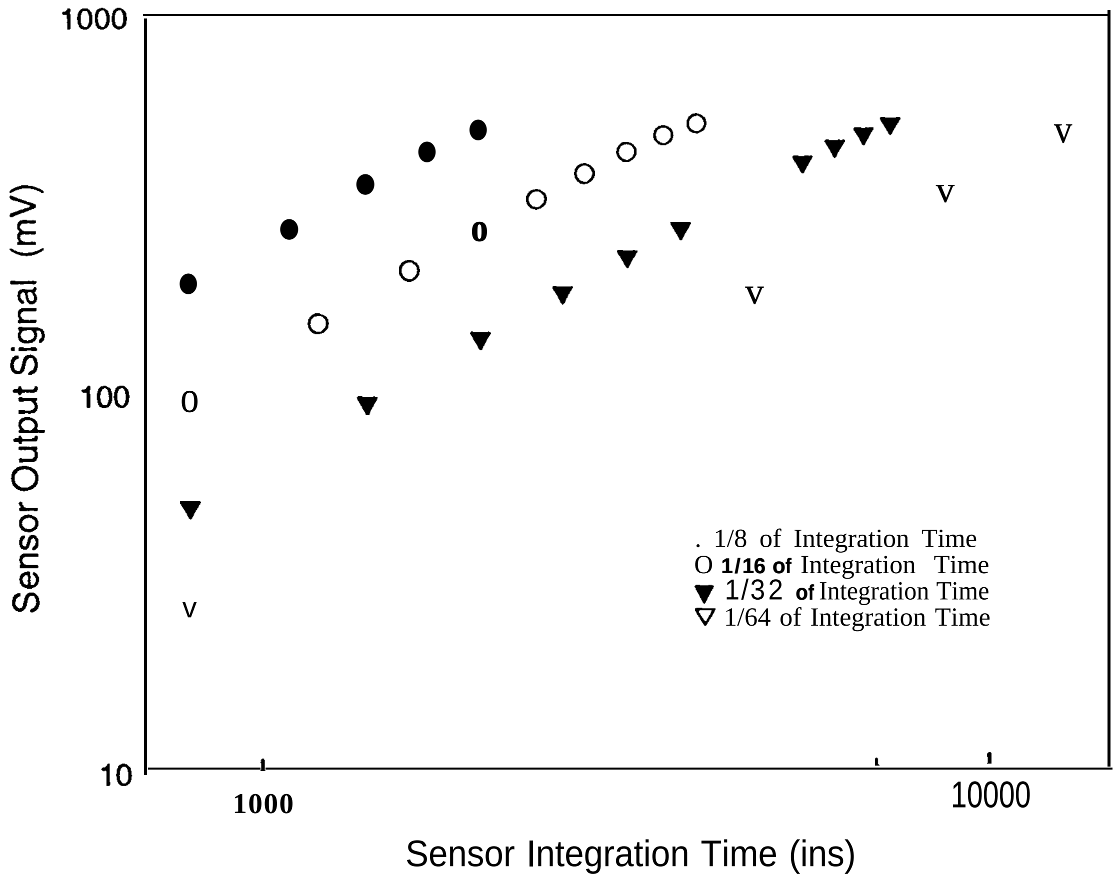


Fig.4. Sensor output as a function of integration time for various exposure sets - a log-log scale plot.